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Original Article

DESIGN AND DEVELOPMENT OF DEPLOYMENT MECHANISM FOR 1 METER RESOLUTION SPACE TELESCOPE

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ABSTRACT

Deployable telescope is a concept where the space telescope remains in stowed position in the payload fairing of launch vehicle and deployed in orbit to its final form. An initial concept demonstration model of the mechanism was developed as a part of first phase of the project. Phase 2 of the project is aimed at developing a mechanism for 100 micron deployment accuracy in separation and 100 arc seconds in alignment. Scope of the present work is related to Phase-2 of the project. Two models were made as a part of phase-2. Design of elements of deployment mechanism and its characterization was done. Assembly and separation characterization is carried out for both models of phase-2 deployment mechanism. Details regarding the design of mechanism elements, analysis, realization and characterization are covered in this paper.

KEYWORDS: Deployable, Space Telescope & Accuracy

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INTRODUCTION

A telescope is an instrument that aids in the observation of remote objects by collecting electromagnetic radiation (such as visible light) [1]. There are the two main types of optical telescopes that operate in visible light. [2]

- Refractors or Dioptrics: This is the type of telescope that provides a view by looking through a lens or series of lenses that focus at an eyepiece.
- Reflectors or Catoptrics: This provides a view by reflecting the image of a primary mirror that is parabolic and focuses the light into the eyepiece.

A Ritchey-Chrtien telescope (R-C type telescope) is a specialized Cassegrain telescope invented in the early 20th century that has a hyperbolic primary mirror and a hyperbolic secondary mirror designed to eliminate optical errors [3]. A conventional R-C type telescope is shown in figure 1.

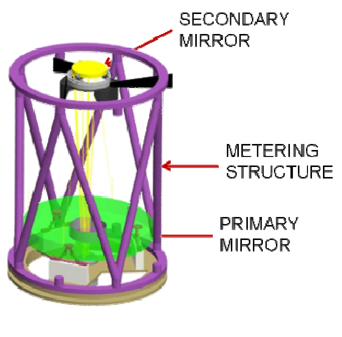

Figure 1: Conventional Telescope.

It consists of a Primary mirror which receives the light and focuses it on the secondary mirror. The secondary mirror reflects and converge the light on the focal plane of the telescope which is further detected and processed by the electronic systems. Elements of telescopes are primary mirror, secondary mirror and eyepiece.

The physical separation between the mirrors is provided by a structure known as metering structure. As seen the metering structure has a monolithic construction, which becomes a disadvantage as the size of the telescope increases with the increased resolution requirement. A deployable telescope consists of a mechanism, which enables the telescope to be stowed in the launch vehicle fairing and deployed in orbit, thus bigger size telescopes can be designed employing such mechanism. The telescope can have a deployable metering structure, deployable mirrors or both of them in one telescope. Here a telescope having deployable metering structure is developed. The metering structure is replaced by a deployment mechanism.

Advantages

A deployable telescope provides following advantages compared to a conventional telescope:

- Enables design of large aperture telescopes which can be accommodated in the launch vehicle fairing
- Less mass
- Higher orbits can be utilized
- In a single launch, more than one payloads can be accommodated, thus shrinks budget to a great extent
- Use of casual materials as compared to ultra stable exotic materials can be done.

As shown in the line diagram in figure 2 and explained below, following two parameters are important for the metering structure performance:

- **Separation:** The metering structure should be such that it should maintain a constant distance between the centers of the primary and secondary mirrors of the telescope, this distance is stated as the separation between them. In general for a telescope operating in the visible spectrum demands separation accuracy within 10 microns.

- **Alignment:** The angle between the optical axes of the two mirrors is in general required to be maintained within 10 arc seconds of alignment

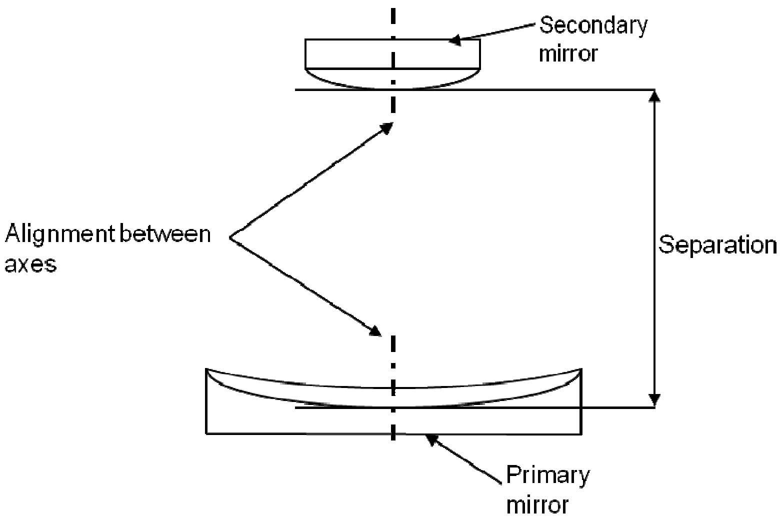

Figure 2: Line Diagram for Telescope.

OVERVIEW OF DEPLOYMENT MECHANISM

System Specifications

Deployment mechanism is to be developed for a telescope, having following specifications:

- Separation between mirrors = 1000 mm
- Volume reduction while launch $\geq$ 70%
- Frequency of the system in stowed condition >100 Hz.
- Frequency of the system in deployed condition > 10 Hz.
- Stresses while deployment < allowable limits
- Moving mass = 4 kg.
- Accuracy in Separation $\leq 5\mu$
- Accuracy in Tilt $\leq$ 10 arc seconds

Design Requirement

The deployment mechanism in general consists of following basic elements as discussed below:

Rigid Links*:* These are the elements which impart the required separation. The rigid links should have lower mass and good stiffness.

Actuators*:* These elements are responsible for deploying the mechanism, i.e. they impart motion to the mechanism.

An ideal actuator should posses following characteristics:

- It must consume minimum power.
- It should have high reliability and repeatability in its performance.
- It should cause complete deployment of the mechanism.
- It must not give shock to the mechanism.

An important fact of a deployment mechanism is that its deployment has to occur completely rather than precisely, post deployment stability is the most important factor for deployment mechanisms. A simple passive device can serve the purpose of an actuator. For the present a helical torsion spring is used as an actuator.

- **Joints*:*** It imparts the required degree of freedom to the mechanism. Ideal characteristics of the joints desired are listed below:

- Friction at joints should be minimum
- Load cycling response should be linear
- Free play should be minimum

A revolute joint is used in this design. A revolute joint consists of pin, hub, tang, clevis, bearings, and bush.

- **Latch*:*** It locks the mechanism in its final position after complete deployment has occurred. It is responsible for locking the mechanism in the final deployed position. Following considerations have to be taken in the design of

latch:

- There should be minimum interference to motion before locking occurs
- Locking should not cause much shock at the moment of locking
- The latch should have linear load-cycling response
- It should be easily resettable and should have very much reliable operation.

Hold Down & Release Mechanism (HDRM)

The HDRM will lock the system in stowed condition during launch and release it in orbit. The HDRM design should be such that the natural frequency of the system should be above 100 Hz.

DEVELOPMENT OF DEPLOYMENT MECHANISM

The mechanism can be realized with many variations to achieve the desired functionality. Development work is carried out in different phases. Phase-1 was already completed to achieve 500 micron accuracy in separation. Phase 2 is aimed to achieve 100 micron accuracy in separation and 100 arc seconds accuracy in alignment.

Phase 1

Here the Deployment Mechanism (DM) has three legs as shown in figure 3, each consisting of following elements revolute joint, rigid link having round c/s, two side two point latch mechanism and torsion spring as an actuator. Separation characterization carried out for DM phase-1 and deployment accuracy in separation is found out to be 500 micron.

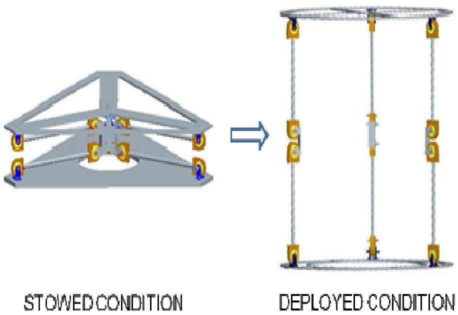

Figure 3: Deployment Mechanism: Phase 1.

Phase 2

This model has a single link in the mechanism in order to reduce the number of joints and related complexities. Modifications exist in the design of latch mechanism, joint and link. The mechanism consists of a primary link, secondary link, joints, actuator-damper, latch mechanism and HDRM. DM in stowed and deployed condition is shown in figure 4.

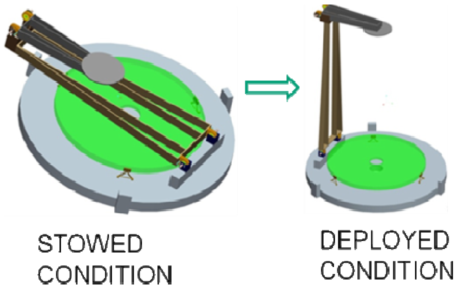

Figure 4: Deployment Mechanism: Phase 2.

Design of Joint

The joint assembly consists of following elements:

- Clevis
- Tang
- Double row angular contact bearing
- Hub and hub lock

Double row angular contact ball bearing is used because it gets self aligned during working this reduces free play. Bearing is press fitted on hub and hub lock is mounted from the opposite end. Instead of pin in deployment mechanism phase 1 here hub and hub lock is used. Due to the hub and hub lock positive locking is done that minimize free play. Tang is mounted press fitted on bearing and whole assembly is done with hub and hub lock at one end of clevis this reduces friction. There are holes for mounting of pin for torsion spring holding. All elements of joint are shown in figure 5.

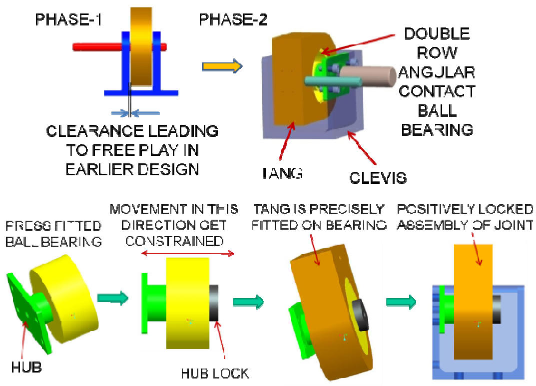

Figure 5: Design of Joint.

Free play is measured for joint assembly and it is about 20-25 micron.

Design of Rigid Link

For the rigid link with joint, if there is free play at joint then that will magnify at the end of link so separation accuracy is not maintained. To overcome the magnification effect of free play at joints, it is decided to use concept of virtual joint and A-Frame structure as a rigid link for deployment mechanism.

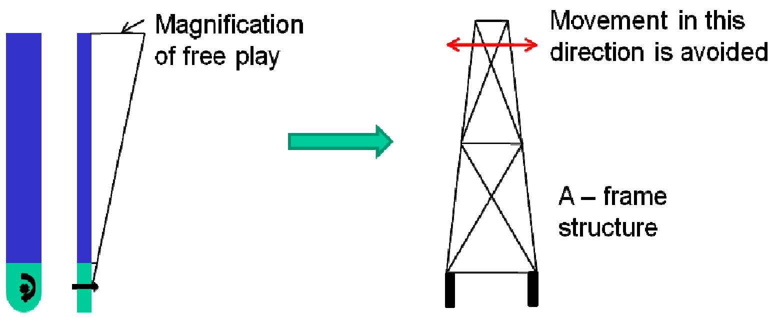

Figure 6: Design of Rigid Link.

Design of Latch Mechanism

Problem with pin and barrel assembly of latch mechanism in model 1 of phase 2 is that there is cylinder in cylinder movement so there is clearance in between them. Pin in barrel is actuated using compression spring. Because of clearance

in between pin and barrel free play is present after the deployment as shown in figure 7.

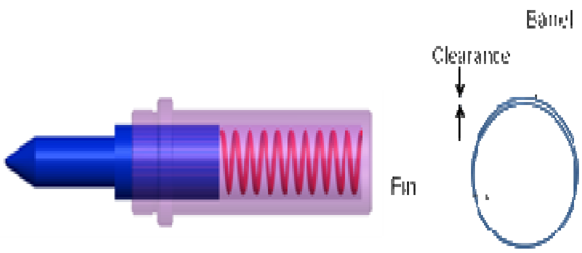

Figure 7: Latch Pin and Barrel Assembly with Compression Spring.

To avoid this linear guide way based latch mechanism is developed. Elements of latch mechanism are locator, piston lock, mounting block, compression spring, stopper, base mounting and linear guide way and ball transfer unit as shown in figure 8.

Linear Guide way itself has around 2 micron accuracy. As there is no clearance during movement of linear guide way so free play after locking is avoided. Mounting block is mounted in linear guide way. On either side of mounting block spring, stopper and piston lock assembly is present to actuate locking mechanism. Locator is present at another side of mounting block which get inserted into locking hole during latching. Locater is designed in such a way that there is minimum clearance between locator and locking hole. Shape of Locator is made taper so it gets positively locked.

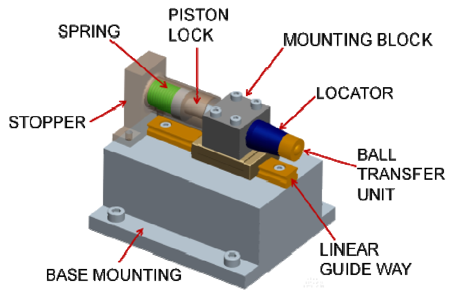

Figure 8: Design of Latch Mechanism.

There is locking tang fastened at the centre of the A-frame structure. Holes are drilled on both side of locking tang for latching. Latch mechanism is mounted on both side of locking tang. So there are two assembly of latch mechanism to avoid unbalance during locking because of impact force exerted by compression spring through locator.

Assembly of Latch mechanism, locking tang, joint and A-frame structure is as shown in figure 9.

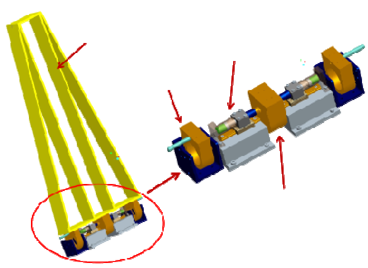

Figure 9: Assembly of Single Link Model.

Assembly of Single Link Setup

All elements of Deployment Mechanism are fabricated as per the design. Fabricated parts are assembled in proper way. The fully developed primary link with the joint and the A-frame linkage is shown in figure 10.

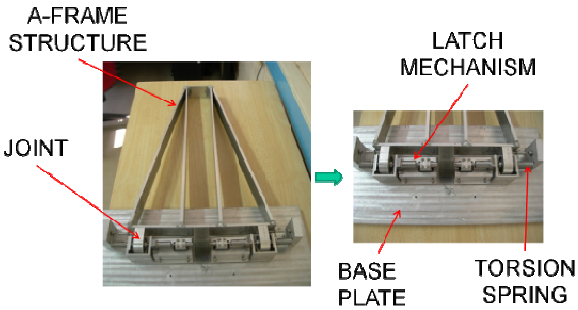

Figure 10: Primary Link with Joints, Link and Latch Mechanism.

Separation Characterization

3D co-ordinate measuring machine ROMER ARM is used for separation characterization. For the measurement two planes are fixed. Plane 1 is assign to fixed plate as a reference. Plane2 is assign to the A-frame which has rotational motion during deployment as shown in figure 11. For separation characterization angle is consider as a parameter for measurement.

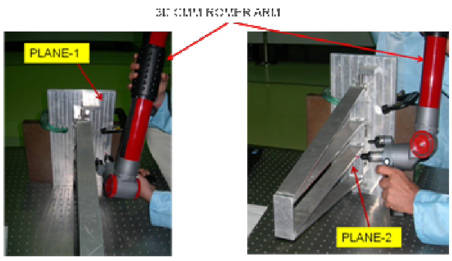

Figure 11: Separation characterization using ROMER ARM for DM: Model 2 of phase 2.

Results after measurements with ROMER ARM are shown in table 1.

The deployment of mechanism is done freely that means damper is not present. So deployment is sudden and exerts impact force after latching. From table, it seen that change in separation decreases continuously that is from 488 micron to 263 micron. Problem faced in this activity is shaking of deployment mechanism during measurement when ROMER ARM probe is bringing in contact with plane 2. Another problem is indentation present after latching. It is proposed that use of spring damper assembly for slow deployment of mechanism.

Table 1: Results of Separation Characterization using 3D CMM Romer Arm for Deployment Single Link Setup

Sl. No.	Free Deployment (degree)	Separation (mm)	Change in Separation (mm)
1	87.4673	499.512	0.488446339
2	87.2277	499.415	0.585212429
3	87.4308	499.497	0.502623467
4	87.4959	499.523	0.477479335
5	87.5046	499.526	0.474167908
6	87.6322	499.573	0.426923554
7	87.7359	499.61	0.390353309
8	87.8776	499.657	0.343028283
9	87.9738	499.687	0.312641017
10	88.1417	499.737	0.262980243

Door closer is used as a spring damper unit for deployment of mechanism. It is decided that use of potentiometer and LVDT for repeatability test of deployment mechanism.

Repeatability Test using LVDT and Potentiometer for DM with Linear Guide way Based Latching and Spring- Damper Unit:

Door closer is used as prototype of spring damper assembly for deployment mechanism. Spring-damper unit is mounted on base plate. Assembly of spring damper unit and A-frame structure is done in such way that A-frame gets deployed with uniform angle that means not get twisted during deployment. Both A-frame and spring damper unit are mounted on angle plate which is stiff enough to sustain load coming during deployment of mechanism. This whole unit is mounted on precise hole table which is highly rigid. Latch mechanism based on linear guide way is used. Assembly is done for deployment mechanism with linear guide way based latching, spring damper unit and angle plate. Experimental set up for repeatability test of deployment mechanism having spring-damper unit, linear guide way based latching using potentiometer and LVDT is shown in figure 12.

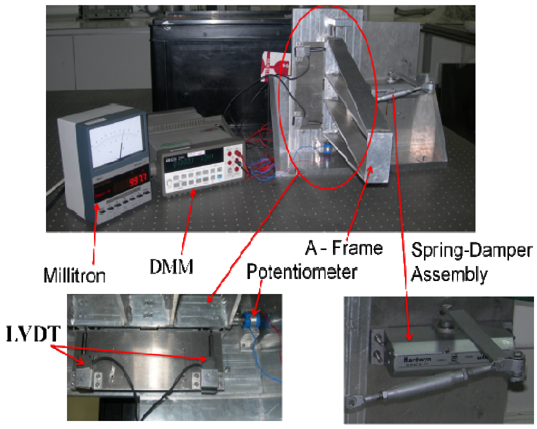

Figure 12: Experimental Setup for Repeatability Characterization.

From characterization of potentiometer, it is observed that for change in 0.00001kohm resistance, change in angle is 65 arc seconds. So potentiometer is not useful for repeatability test as objective of the activity is to measure repeatability within range of 30-50 arc seconds. It is decided to use LVDT for repeatability test of deployment mechanism which has 1 micron accuracy in separation and 1 arc second accuracy in alignment.

Results for repeatability test of Deployment Mechanism using LVDT for linear guide way based latching is as shown in table 2.

Table 2: Results for Repeatability Test of Deployment Mechanism using LVDT

Sl. No.	LVDT-A (µ)	LVDT-B (µ)
1	2394.6	1931.1
2	2395	1930.6
3	2408.4	1943
4	2345.6	1933
5	2367.9	1954.4
6	2411	1996.7
7	2393.3	1986.6
8	2683.5	2275.3
9	2637.2	2230.1
10	2630.2	2219.6

From results it is observed that range of repeatability is for LVDT-A is 337.9 micron and for LVDT-B is 344.7 micron.

Problems Faced in Linear Guide way based Latching

Wear at Latch Pin and Mating Hole

During locking latch pin get inserted into mating hole of locking tang. This happens during every deployment results in wear problem at the interference. Wear results in deviation from actual position of deployment mechanism during each deployment which affect on accuracy in separation and alignment.

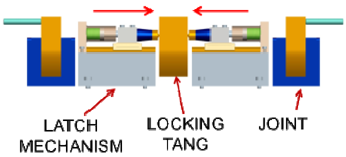

Figure 13: Problems faced in Linear Guide way based Latching.

1. Lack of simultaneous latching:-

There are two linear guide ways based latch mechanism mounted on base plate on each side of the locking tang. Two latch mechanisms are set in such way that they perform locking operation at same instant. But during the deployment, latch mechanism gets disturbed, so there is a change in alignment. So, lag is present between two latch mechanisms during deployment.

Manual Release of Latch Mechanism after Locking

After every deployment, resetting of latch mechanism is done to achieve its original position for locking during next deployment. Manual releases of latch mechanism disturb the assembly and there is misalignment in two latch mechanisms results in no simultaneous locking.

Hard Point Locking:

Hard point locking is used to overcome drawbacks of linear guide way based latching. Concept of hard point locking is shown in Figure (14). In hard point locking, one rigid reference point is used which is at the final required position. After deployment of mechanism link rotates and rest at the rigid reference point attains final required position. That rigid reference point is called hard point and locking is called hard point locking. Assumption is made that hard point is rigid enough having negligible deformation.

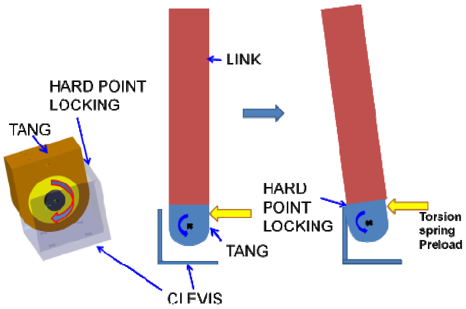

Figure 14: Hard Point Locking.

In our existing mechanism, clevis edge is considered as hard point. Tang surface is rest at the edge of clevis and remain at final position because of preload of torsion spring. This hard point locking is implemented in our existing mechanism and repeatability test is carried out. Results of the repeatability test are as shown in Figure (15).

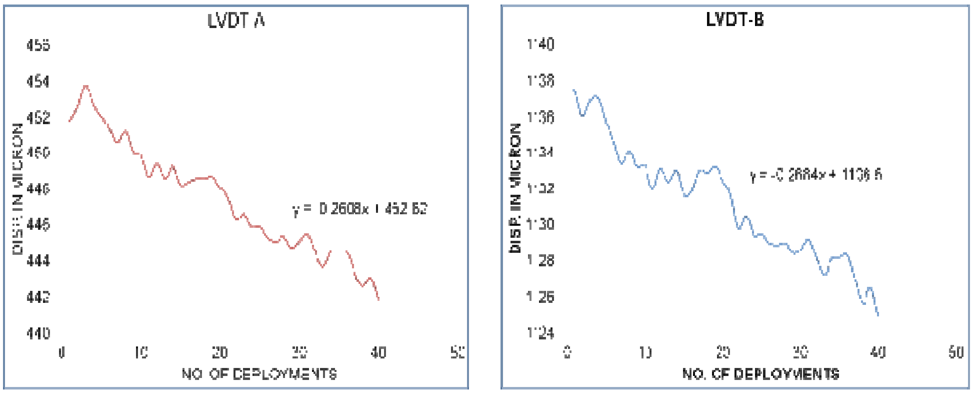

Figure 15: Results of Repeatability Characterization for Hard Point Locking.

DISCUSSIONS

From nature of graph, it is observed that displacement (in micron) is continuously decreasing. There are two errors which contribute for such a nature of graph given below:

Global Error: Global error is because of following reasons,

- Material removal at interface of clevis edge and tang surface
- Variation in force offered by the spring damper assembly

So, it is decided to change tang and clevis as there is material removal at the interface. Force of spring-damper is of very fluctuating nature. For upcoming repeatability tests, gravity field is used for deployment. Gravity force is remaining constant during every deployment.

Local Error: This is because of assembly free play or hysteresis etc.

To avoid material removal error, it is necessary to made contact surface as a hard interface. Initially AL6061-T6 material is used for tang and clevis then it is replaced by SS-304 material as it is hard than AL6061-T6. All the sharp edges of tang and clevis which will be in contact are made round as shown in figure 16.

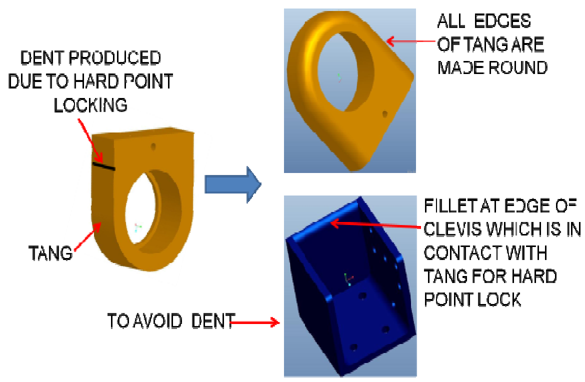

Figure 16: Change in Tang and Clevis.

Repeatability test is carried out after change in tang and clevis. Results after Change in Tang and Clevis under gravity force for deployment as shown in figure 17. Results are obtained for 100 deployments of mechanism under gravity force. Graph shows the Maximum and Minimum reading of the LVDT is 2050µ and 2047µ. The repeatability is within the range of 3µ.

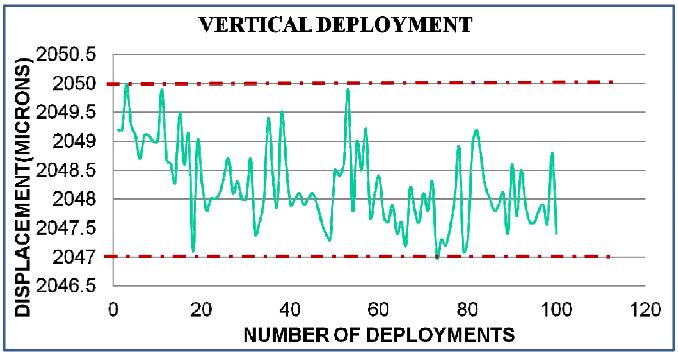

Figure 17: Results after Change in Tang and Clevis Under Gravity Force for Deployment.

From the above reputability test, it decided to eliminate material removal error as possible by hardening of tang and clevis. Plasma-Nitriding of tang and clevis is done to increase surface hardness. Repeatability test is carried out with hardened tang and clevis. Results for the test are as shown in figure 18.

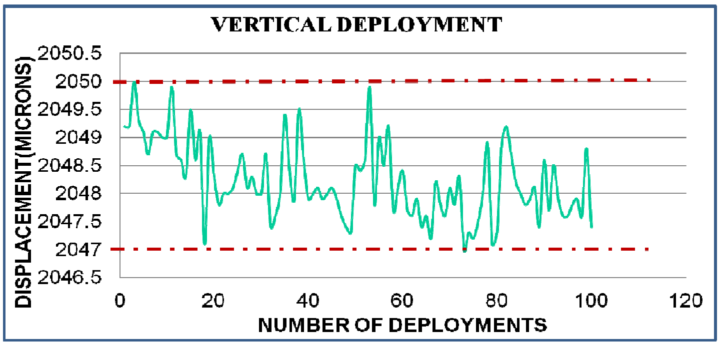

Figure 18: Results after Plasma-Nitriding of Tang and Clevis.

As can be seen from the graph, the maximum and minimum reading of the LVDT is 1185.2μ and 1183.2μ.

Thus, the repeatability is within the range of 2μ considering the amplification of the error at the end of the linkage as explained in figure 19 the repeatability at the extreme will be (500/25)*2 = 50 microns.

Thus, based upon these results and extrapolating these values for the complete two link model is shown in figure 19, the final estimated accuracy happens to be around 100 microns.

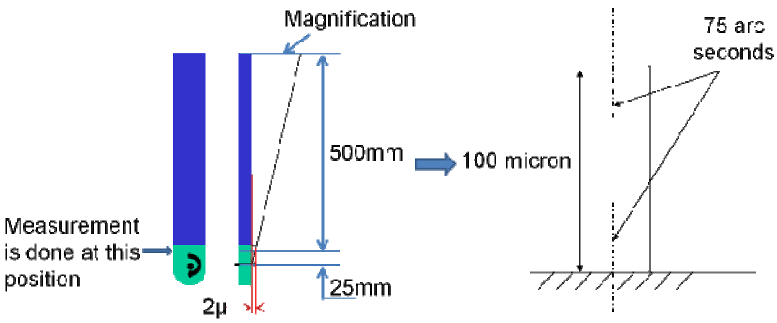

Figure 19: Amplification of Error and Estimated Errors in Separation and Alignment.

Final Estimated Accuracy in System:

Separation =**100 μ**

Alignment =**75 Arc Seconds**

CONCLUSIONS

- Verified accuracy for the single link set up and estimated accuracy in separation is 100 micron and accuracy in alignment is 75 arc seconds for 1-meter separation deployment mechanism.
- It is decided to use constant torque spring as an actuator and Eddy Current Damper for deployment mechanism for space telescope.

FUTURE SCOPE

Hold down and release mechanism: It is proposed that design hold down and release mechanism in such way that it increases stiffness (frequency) of the system during payload fairing.

Eddy current damper: Deployment of deployment mechanism without damper gives sudden impact after latching. This cause indentation and permanent change in separation value. It is proposed that design eddy current damper for gradual deployment of deployment mechanism. As eddy current damper does not require oil or any type of fluid, it is selected for space telescope. Parametric study of damper will be done.

Zero-g set up for deployment mechanism: For exact separation, characterization of deployment mechanism zero-g set up is necessary. So it is decided that to design exact simulation set up for zero gravity environment.

Mounting of primary mirror and secondary mirror: Mounting of primary mirror and secondary mirror at the deployment mechanism will be done in future and characterization will be carried out for the same.

Active correction of deployment mechanism: To achieve final accuracy in separation in alignment as per the system specification, active correction is used for deployment mechanism. Hexapod system will be used for active correction.

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